



Faculty of Engineering

# **MODELING AND CONTROLLER DESIGN OF A BALL AND BEAM SYSTEM**

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# MODELING AND CONTROLLER DESIGN OF A BALL AND BEAM SYSTEM

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This project is submitted in partial fulfillment of  
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Dedicated to my beloved family and friends.

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# ABSTRAK

*Ball and beam system* boleh didapati di kebanyakan makmal kawalan universiti. Ia adalah salah satu model makmal yang terkenal bagi sistem kawalan. Sistem ini terdiri daripada bebola, alur, motor arus terus dan beberapa alat penderia. *Ball and beam system* terbahagi kepada dua tatarajah yang mana alur disokong di tengah dan alur disokong di kedua-dua belah. Bebola bergelek di atas alur secara bebas. Ini menyebabkan sistem menjadi gelung terbuka, tidak stabil dan tidak lurus. Model matematik bagi *ball and beam system* adalah tidak lurus secara semulajadi tetapi mungkin dileluruskan sekitar kawasan mendatar. Walaubagaimanapun, model yang telah dileluruskan masih mewakili kebanyakan sistem nyata seperti penstabilan mendatar bagi sebuah kapal terbang semasa mendarat dan di dalam aliran udara yang bergelora. Terdapat banyak kaedah kawalan yang boleh digunakan pada masalah sistem ini. Di dalam projek ini, kaedah kawalan *PID* dan *State Space* digunakan untuk menyelesaikan masalah ini. Keputusan prestasi optimum yang diperolehi dari kaedah kawalan *PID* dan *State Space* dibandingkan.



# **ABSTRACT**

Ball and beam system can be found in most university control labs. It is one of the most popular laboratory models for control system. The system consists of ball, beam, DC motor and several sensors. There are two configurations of ball and beam system which is the beam is support in the middle and both side. The ball is rolls on the beam freely. This cause the system becomes open loop, unstable and nonlinear. The mathematical model for ball and beam system is inherently nonlinear but may be linearized around the horizontal region. This simplified linearized model, however, still represents many typical real systems, such as horizontally stabilizing an airplane during landing and in turbulent airflow. Many control methods can be applied to this system problem. In this project, PID and State Space control methods are used to solve this problem. The optimum performance result obtained from PID and State Space control methods are compared.

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# LIST OF ACRONYMS

AC	-	Alternative Current
A/D	-	Analog to Digital
d	-	Lever arm offset
DC	-	Direct Current
DSP	-	Digital Signal Processing
g	-	Gravitational acceleration
GND	-	Ground earth
J	-	Ball's moment of inertia
k	-	Constant
L	-	Length of the beam
LQG	-	Linear Quadratic Gaussian
LQR	-	Linear Quadratic Regulator
M	-	Mass of the ball
MATLAB	-	Matrix Laboratory
MIMO	-	Multiple Inputs Multiple Outputs
MRAC	-	Model Reference Adaptive Control
PD	-	Proportional Derivative
PI	-	Proportional Integral
PID	-	Proportional Integral Derivative

$R$	-	Radius of the ball
$r$	-	Ball position coordinate
$\alpha$	-	Beam angle
$\theta$	-	Motor angle
$\Omega$	-	Ohm
$F_{rx}$	-	Force due to ball rotation
$F_{tx}$	-	Force due to translational motion
$K_D$	-	Derivative gain
$K_I$	-	Integral gain
$K_P$	-	Proportional gain
$T_D$	-	Derivative time
$T_I$	-	Integral time
$V_{source}$	-	Voltage source

# **CHAPTER 1**

## **INTRODUCTION**

### **1.1 Ball and Beam System**

The ball and beam system is also called ‘balancing a ball on a beam’. It is one of the most popular and widely used laboratory models for control systems. It is simple to understand as a system and the control techniques are cover many important classical and modern design methods. Figure 1.1 is illustrating the ball and beam system.

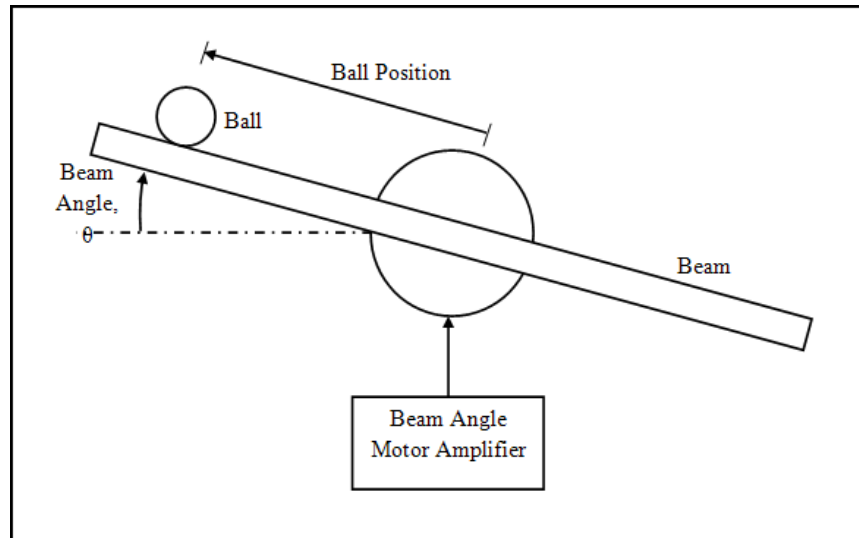


Figure 1.1: Ball and Beam System Diagram (Wellstead, 2008)

Generally, the ball and beam system is connected to real control problem such as horizontally stabilizing an airplane during landing and in turbulent airflow. There are two degrees of freedom in this system. First is the ball rolling up and down on the beam and second is the beam rotating through its centre axis. The main purpose of the system is to control the position of the ball along the beam to a desired position by manipulating the angular position of the DC motor. The position of the ball on the beam can be measured using a special sensor. The control voltage signal is send to the DC motor through a power amplifier and then the torque generated by the motor drive the beam to rotate to the desired angle. Thus, the ball can be located at the desired position.

The ball and beam system is open loop and important to point out that it is unstable and nonlinear because the ball position changes with acceleration without limit for a fixed beam angle. Unlike the linear dynamic systems, nonlinear systems

often possess structural properties that make them very difficult to control (Wellstead, 2008).

The unstable problem of the system can be solved by closing the open loop with a feedback controller. There are many types of feedback control can be used to stabilize the system such as Proportional Integral Derivative (PID) Control, State Space Method Control and Model Reference Adaptive Control (MRAC). The nonlinear property is not significant when the beam only deflects a small angle from the horizontal position (Wei, 2007).

## **1.2 Problem Statement**

Most control problems that can meet in practical world are straightforward to control. For a fixed input signal produce more or less constant of output. Unstable and feedback control is to make the operation operate safely. Many modern industrial processes and technological system as such unstable could be used without stabilizing feedback control (Wellstead, 2008). One important practical example of unstable systems is the control of an aircraft during vertical take-off or during landing and in turbulent airflow. The angle of thruster's jets is needed to control continually to prevent the aircraft tipping. So feedback control is required.

### **1.3 Objectives**

The objectives of this project are listed in the following:

- i. To obtain a mathematical model of the ball and beam system.
- ii. To design two controllers to control and stabilize the nonlinear ball and beam system.
- iii. To design a Simulation control model of the system using MATLAB software.
- iv. To compare the two controllers in settling time less then 3 seconds and overshoot less then 5%.
- v. To compare four basic algorithm of PID controller.

### **1.4 Scope of the Project**

The purpose of this project is to design two controllers as a feedback control to control and stabilize the unstable ball and beam system. The ball and beam system is often used as a bench mark problem for many different control systems. The ball rolling freedoms on the beam with acceleration make it become unstable. The system is represented in mathematical model. In this project, the control task is to stabilize the system. Two controllers have been chosen to perform this task, which are PID Controller and State Space Controller. MATLAB software is used as the software simulation for the unstable ball and beam system model and the two controllers that have been chosen to solve the system problem.

## **1.5 Project Outline**

This Final Year Project's Report consists of five chapters. The brief information of each chapter is described as below:

### **Chapter 1: Introduction**

This chapter provides a brief introduction of ball and beam system and its operation. The problem statement, objectives and the scope of the project are outlined as well. Besides that, project outline is also provided in this chapter.

### **Chapter 2: Literature Review**

This chapter reviews some literature on the ball and beam system and the controllers that can be used to solve the system problem. Five controllers are listed out in this chapter, which are PID Control, State Space Control, MRAC, Fuzzy Control and Neural-Network Predictive Control.

### **Chapter 3: Methodology**

This chapter explains how the project is able to complement the problem stated and expected problem during project. It also provides the information of the methods used in the project. Start with describing the theoretical prediction methodology that is mathematical model for ball and beam system. It also presents the PID Control and State Space Control design implementation.